28

The COMPASS System: Computer-Assisted Surveying and Mapping for Archaeological Fieldwork

Andrew Weiss*

28.1 Introduction

One of the most important components of archaeological data is the spatial context. Archaeologists are constantly examining the location and distribution of data at a variety of scales: point proveniencing of individual artifacts; square level mapping and section drawing; site wide topographic, architectural, and distribution maps; and regional maps covering tens to hundreds of kilometres. The adoption of Computer-Assisted Surveying and Mapping (CASM) can dramatically enhance the archaeologist's ability to collect, manipulate, analyze, and display spatial data. The ongoing development of the COMPASS system (COmputer Mapping Program for Archaeological Sites and Survey), undertaken at MASCA since 1986, is beginning to fulfill this potential.

COMPASS is an integrated system comprised of several hardware and software modules designed for 4 major tasks:

1. Data collection using electronic surveying instruments, field data recorders, traditional mapping techniques, and the digitization of existing plans, maps, and photographs.

2. Data processing, including survey data editing, coordinate geometry, and the merging and manipulation of thematic data associated with measured spatial objects.

3. Interactive map display and analysis of selected data elements and statistical representations of the dataset, providing a tool for exploring stratigraphic and spatial relationships, and creating thematic maps showing these relationships. One use is to provide a spatial equivalent to exploratory data analysis in statistics (Tukey 1977), in other words, 'playing with the data.'

4. Generation of hardcopy and machine readable maps in a variety of formats suitable for publication and presentations.

The overall approach of COMPASS is to complement traditional archaeological techniques rather than replace them with a completely automated system. System development to date has concentrated on automating certain tasks within the mapping process that are mechanical and repetitive, such as measuring distances and angles, performing trigonometric computations, recording and transcribing data, and X/Y point plotting—in other words, tasks that computers are very good at, and people are not. The incorporation of Computer-Assisted Drafting (CAD) aids in the mechanics of drawing maps, allows quick modification and experimentation with different map compositions, and facilitates the generation of several specialized maps from a common base map.

---

* Museum Applied Science Center for Archaeology (MASCA)
The University Museum
University of Pennsylvania
33rd and Spruce St.
Philadelphia, PA 19104
USA

Many of the tools and procedures for working with spatial data can be applied across several scales, ranging from point proveniencing individual artifacts up to regional maps. This gives two major advantages: the investment in costs and learning can be applied to a wider set of problems; and the entire spatial dataset, at every scale, can be maintained and integrated within a single consistent format.

Important requirements are that COMPASS be widely accessible to archaeologists, thus cost effective (read *inexpensive*) and easily learned, and that the system can be operated in a field laboratory setting. These specifications argued for using a standard microcomputer rather than a mainframe, minicomputer, or a UNIX based engineering workstation system. COMPASS is built around the Apple Macintosh family, which provides strong graphics capabilities, a consistent user-interface, and standard file formats across programs. The Mac Plus and SE are easy to transport and have enough computing power for field applications. At a central laboratory a Mac II has the power to support interactive colour graphics and computationally intensive tasks. The overall system is modular at both the hardware and software level, allowing each component of the system to be used standalone to perform its specific task, while making it easier to integrate different hardware and application software.

28.2 System Configuration

28.2.1 Hardware

The COMPASS system has 3 key hardware components (Fig. 1.1). An electronic Total Station is used to measure the 3-dimensional coordinates of survey points and excavation data. In the field the total station is linked to an Hewlett Packard HP-71B handheld computer, which can be connected to battery powered peripherals such as printers, disk drives, cassette drives, and RAM disks. In the laboratory the Macintosh is used to store, manipulate, and plot spatial data on a dot matrix or laser printer.

The surveying instrument we are currently using is the TOPCON GTS-3B Total Station. This instrument integrates an electronic theodolite measuring to 5 seconds of an arc; an electronic distance measurer, or EDM, which uses a low power infra-red laser to measure distances up to 2 kilometres with a precision of a few centimetres; and a microprocessor, which instantly calculates transformations among polar, cylindrical, and cartesian coordinate systems, allows the occupied station coordinates and instrument height to be preset within the total station, and controls communications to a data collector.

Distances are measured by focusing the laser on a small prism. Multiple prism sets can be used to increase the range. Angles, distances, and coordinate values are all displayed digitally, eliminating vernier scales and stadia readings. This increases both the accuracy and the speed of measurements, and substantially reduces mistakes.

The HP-71B has from 33K up to 256K of nonvolatile memory which retains data while the computer is turned off. Programs are written in a powerful version of BASIC specifically designed for instrument control and scientific processing. The advantage of using the HP-71B rather than a specialized data collector is that customized programs can be written to support systematic protocols for measuring different kinds of archaeological features, and to incorporate archaeological recording systems (artifact numbers, provenience designations, etc.) into the data file. There are several HP-71B application packages available on plug in Read-Only-Memory (ROM) modules for surveying, data communications, and mathematics, as well as many applications available on disk or cassette. The ability to connect printers and mass storage devices is also an extremely important feature. Since the spatial context of archaeological data is generally destroyed through the removal of artifacts and
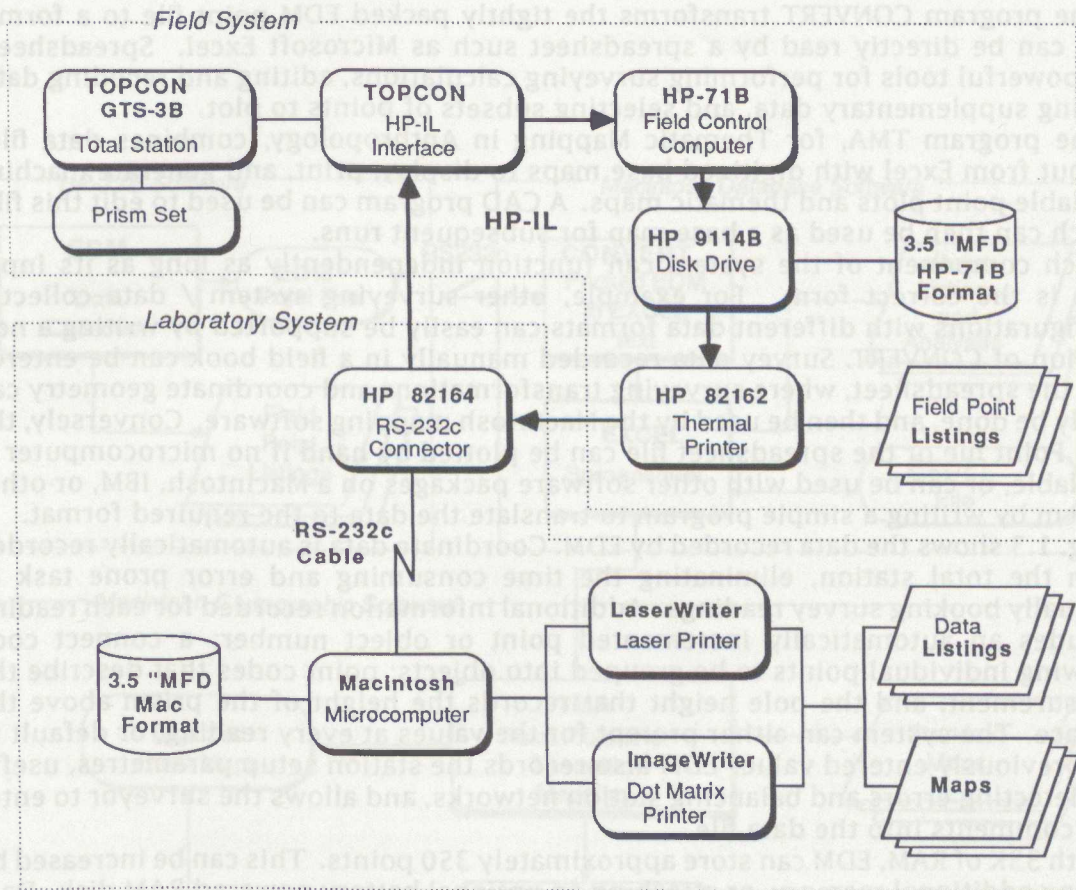
Field System

TOPCON GTS-3B — Total Station
Prism Set

TOPCON HP-IL Interface

HP-71B Field Control Computer

HP-IL

HP 9114B Disk Drive

3.5 "MFD HP-71B Format

Laboratory System

HP 82164 RS-232c Connector

HP 82162 Thermal Printer

Field Point Listings

RS-232c Cable

3.5 "MFD Mac Format

Macintosh Microcomputer

LaserWriter Laser Printer

ImageWriter Dot Matrix Printer

Data Listings

Maps

Figure 28.1: Hardware configuration of the COMPASS system.

continuing excavation, ensuring that data is secure by either printed hard copy or mass storage backup is of the highest priority.

This total station costs in the order of $12,000 and upwards, while the HP-71B data collection computer and peripherals add an additional $2,000 to $3,000.

28.2.2   Software

The software components of the COMPASS system (Fig. 1.2) combine industry standard spreadsheets and drawing programs with software developed at MASCA. HP-71B software includes the instrument control program EDM, and a set of utilities for editing and printing data files in the field. EDM generates an ASCII file which can easily be transferred to other systems over a RS232c communications interface.

The program CONVERT transforms the tightly packed EDM point file to a format that can be directly read by a spreadsheet such as Microsoft Excel. Spreadsheets are powerful tools for performing surveying calculations, editing and recoding data, adding supplementary data, and selecting subsets of points to plot.

The program TMA, for Thematic Mapping in Anthropology, combines data files output from Excel with digitized base maps to display, print, and generate machine readable point plots and thematic maps. A CAD program can be used to edit this file, which can then be used as a base map for subsequent runs.

Each component of the system can function independently as long as its input data is the correct form.   For example, other surveying system / data collector configurations with different data formats can easily be supported by writing a new version of CONVERT. Survey data recorded manually in a field book can be entered into the spreadsheet, where surveying transformations and coordinate geometry can easily be done, and then be used by the Macintosh mapping software. Conversely, the EDM Point file or the spreadsheet file can be plotted by hand if no microcomputer is available, or can be used with other software packages on a Macintosh, IBM, or other system by writing a simple program to translate the data to the required format.

Fig. 1.3 shows the data recorded by EDM. Coordinate data is automatically recorded from the total station, eliminating the time consuming and error prone task of manually booking survey readings. Additional information recorded for each reading includes an automatically incremented point or object number; a connect code allowing individual points to be grouped into objects; point codes that describe the measurement, and the pole height that records the height of the prism above the surface. The system can either prompt for the values at every reading, or default to the previously entered value. EDM also records the station setup parametres, useful for detecting errors and balancing station networks, and allows the surveyor to enter text comments into the data file.

With 33K of RAM, EDM can store approximately 350 points. This can be increased by adding additional memory, or attaching an optional battery powered RAM disk. Data can also be saved in the field on the battery powered 3.5 inch disk drive. Hardcopy can be produced on an optional battery powered thermal or inkjet printer, useful in recording foresights to a new station and producing a printed list for data which cannot be reshot, such as artifact point proveniences. Artifacts can be bagged along with a printed slip showing their coordinates, and assigned number and type.

TMA can generate X/Y plots of spatial data with point labels (elevations, artifact numbers, etc.) and connect grouped points with lines, saving hours of tedious and error prone labour. The user has full control over the scale, the location of the viewing window within the overall map, and the frequency of grid lines. Printed maps (Fig. 1.4, see also Figs. 1.5, 1.6, 1.12, 1.13, and 1.15) are organized into one or more map sheets each of which contains a map window, the corner coordinates of the window, a scale bar, and optional titles and labels. These sheets can be combined into a mosaic for large format maps.
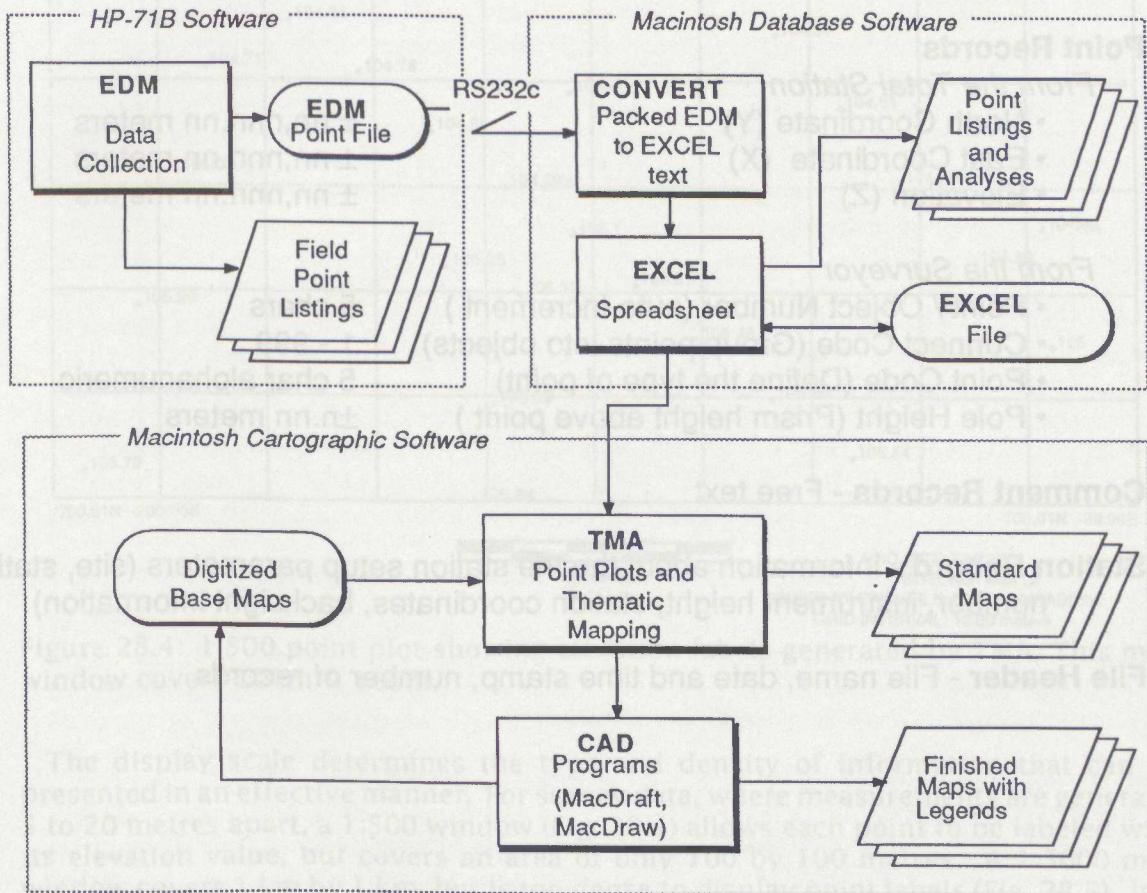
Figure 28.2: Software configuration of the COMPASS system.

Point Records

From the Total Station
- North Coordinate (Y)   ± nn,nnn.nn meters
- East Coordinate (X)   ± nn,nnn.nn meters
- Elevation (Z)   ± nn,nnn.nn meters

From the Surveyor
- Point / Object Number (auto-increment)   5 chars
- Connect Code (Group points into objects)   1 - 999
- Point Code (Define the type of point)   5 char alphanumeric
- Pole Height (Prism height above point)   ±n.nn meters

Comment Records - Free text

Station Record - Information about the the station setup parameters (site, station number, instrument height, station coordinates, backsight information).

File Header - File name, date and time stamp, number of records

Figure 28.3: Data collected by the HP-71B program EDM.

-600.00N -200.00E   -600.00N -99.99E

.103.48

.103.14

.103.68

.103.88   .103.64

.103.65

103.91

.103.91

.104.15   .104.1

.104.33

.104.36 .104.43

.104.5   .104.53   .104.39

.104.57

.104.64

.104.57

.104.71   .104.74

.104.75

.104.61

.104.85

.105.01   .104.99.105

.104.65

.105.1   .104.82

.105.25   .104.89

.105.33   .105.31

.105.29

.105.46   .105

.105.55

.105.59

.105.72   .105.54

.105.84

-700.01N -200.00E   -700.01N -99.99E

25 meters

PROJECT: TAP'87
SITE: Non Mak La
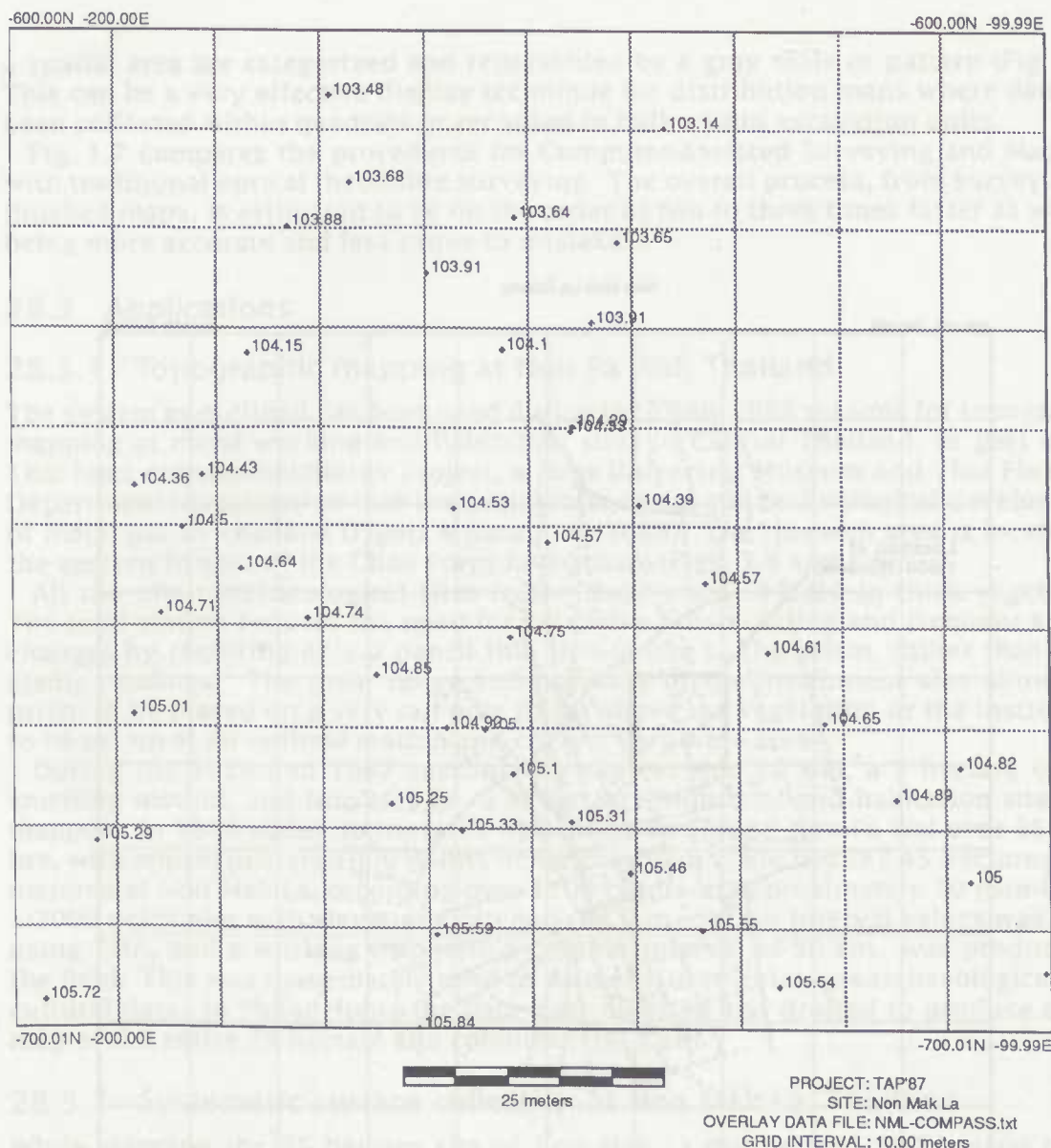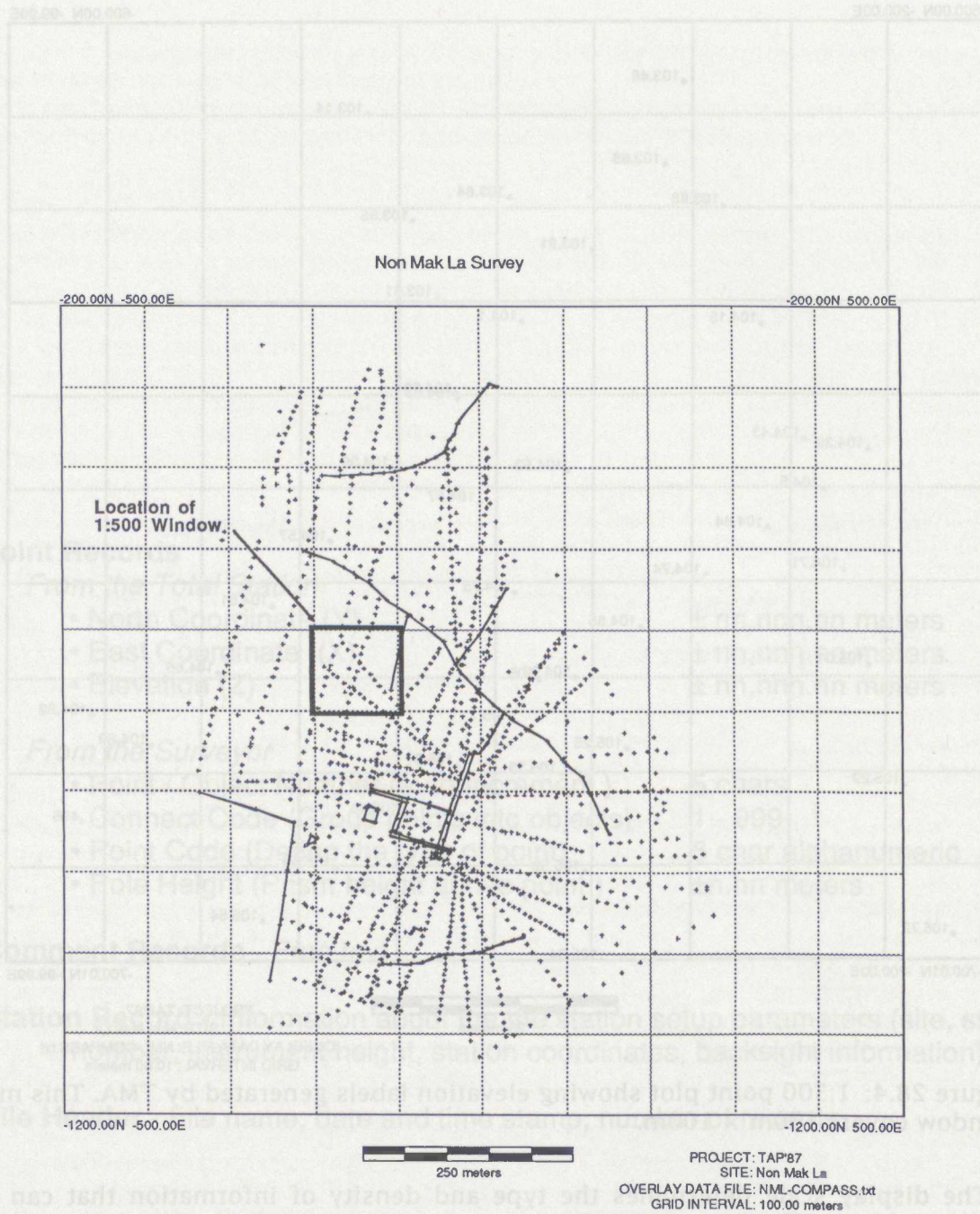OVERLAY DATA FILE: NML-COMPASS.txt
GRID INTERVAL: 10.00 meters

Figure 28.4: 1:500 point plot showing elevation labels generated by TMA. This map window covers 100m × 100m.

The display scale determines the type and density of information that can be presented in an effective manner. For survey data, where measurements are generally 5 to 20 metres apart, a 1:500 window (Fig. 28.4) allows each point to be labeled with its elevation value, but covers an area of only 100 by 100 metres. A 1:5000 map window covers 1 km by 1 km, but is too dense to display point labels (Fig. 28.5). It is useful for showing a general overview of the area, and as a working guide as to what areas have received adequate coverage during survey.

COMPASS also supports thematic mapping, which is the portrayal of a data set in its spatial context by using symbols, colours, patterns, contours, and other graphic techniques (Robinson *et al.* 1984; Bertin 1983). Common archaeological research problems such as activity area analysis, intrasite variation, site catchment analyses, and settlement pattern studies are all ideal applications for thematic mapping. One example of thematic maps are choropleth maps, where data values associated with

Non Mak La Survey

Figure 28.5: 1:5000 point plot generated by TMA, which covers 1000m × 1000m. The location of the 1:500 plot in Fig. 1.4 is highlighted.

a spatial area are categorized and represented by a gray scale or pattern (Fig. 1.6). This can be a very effective display technique for distribution maps where data has been collected within quadrats or recorded in bulk within excavation units.

Fig. 1.7 compares the procedures for Computer-Assisted Surveying and Mapping with traditional optical theodolite surveying. The overall process, from surveying to finished maps, is estimated to be on the order of two to three times faster as well as being more accurate and less prone to mistakes.

28.3 Applications

28.3.1 Topographic mapping at Non Pa Wai, Thailand

The system as outlined has been used during the 1986–1989 seasons for topographic mapping at metal working and habitation sites in Central Thailand, as part of the Thai land Archaeometallurgy Project, a joint University Museum and Thai Fine Arts Department investigation into the prehistoric social and technological development of metal use in Thailand (Pigott & Natapintu 1988). The research area is located on the eastern fringes of the Chao Praya River basin (Figs. 1.8 and 1.9).

All too often archaeological sites in the tropics are covered in thick vegetation. The total station reduces the need for extensive brush cutting and frequent station changes by requiring only a pencil thin line of site to the prism, rather than three stadia readings. The great range and accuracy of the instrument also allows the prism to be placed on a very tall pole to get above the vegetation or the instrument to be set up at an optimal station and cover a very wide area.

During the 1986 and 1987 seasons the sites of Non Pa Wai, a 5 hectare copper smelting mound, and Non Mak La, a 35 hectare industrial and habitation site were mapped. In 1986 about 30 hectares were mapped around Non Pa Wai over 35 man-hrs, with approximately 1000 points being recorded, while in 1987 45 hectares were mapped at Non Mak La, recording over 1200 points in approximately 50 man-hrs. A 1:2000 point plot with elevations categorized into contour interval values was made using TMA, and a working map with a contour interval of 50 cm. was produced in the field. This was immediately used to map environmental, geoarchaeological, and cultural data. In Philadelphia the data was replotted and drafted to produce a final map of the entire 75 hectare site complex (Fig. 1.10).
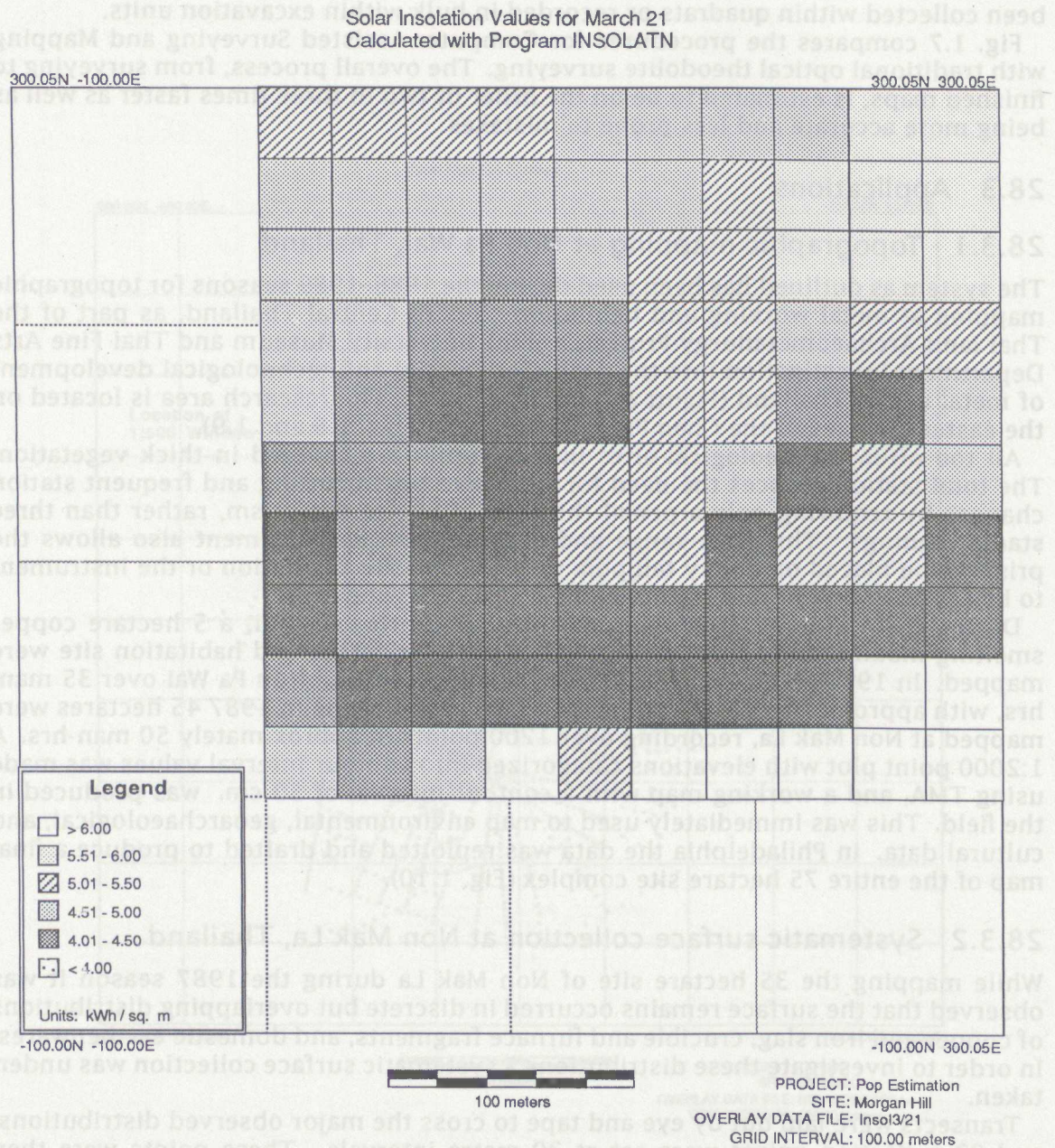
28.3.2 Systematic surface collection at Non Mak La, Thailand

While mapping the 35 hectare site of Non Mak La during the 1987 season it was observed that the surface remains occurred in discrete but overlapping distributions of copper and iron slag, crucible and furnace fragments, and domestic earthenwares. In order to investigate these distributions a systematic surface collection was under-taken.

Transects were laid out by eye and tape to cross the major observed distributions, and 92 collection points were set at 30 metre intervals. These points were then quickly shot in with the Total Station. At each point a circle 1 metre in radius was inscribed in the soil using the dog-leash technique advocated by Binford (1964), the ground cover was carefully removed, and all artifacts were collected, sorted, counted, weighed, and recorded on a field form. Pottery and metallurgical ceramics were then bagged and returned to the field laboratory.

In the laboratory three data sets were combined (Fig. 1.11):

1. A EDM file of the location of each collection unit, transferred to EXCEL.

2. The counts and weights of each artifact class, entered manually into EXCEL from the field recording forms.

Solar Insolation Values for March 21
Calculated with Program INSOLATN

300.05N -100.00E   300.05N 300.05E

Legend

- [ ] > 6.00
- 5.51 - 6.00
- 5.01 - 5.50
- 4.51 - 5.00
- 4.01 - 4.50
- < 4.00

Units: kWh / sq. m

-100.00N -100.00E   -100.00N 300.05E

100 meters

PROJECT: Pop Estimation
SITE: Morgan Hill
OVERLAY DATA FILE: Insol3/21
GRID INTERVAL: 100.00 meters

TMA Release 1.0 ....Museum Applied Science Center for Archaeology (MASCA), The University Museum......... Tue, Dec 1, 1987 ... 2:24 PM

Figure 28.6: An example of thematic mapping—a choropleth map where data values are categorized and displayed as a pattern or gray scale within each spatial unit.

Optical Theodolite.	Computer Assisted Surveying.
FIELD PROCEDURES	
Site Theodolite on the stadia rod.	Site Total Station on the prism.
Read middle stadia line for elevation. Read upper and lower stadia lines for distance. Read vernier scales for horizontal and vertical angles.	Push button. Instrument automatically measures angles, distance, and performs trigonometric conversions to cartesian coordinates.
Record 5 readings in notebook. Add comments. (Readings are in 3-D polar coordinates).	All data automatically stored in HP-71B. Enter Pole Height and/or Point Code, or use defaults. - Add comment record. - Read absolute coordinates North, East, and Elevation or angles and distances in digital form directly from the instrument for quick check. - Optionally print data on battery powered field printer.
Change stations frequently. Cut a lot of brush.	If 350 points taken, then transfer data to portable battery powered disc drive.
	Recharge batteries at end of day.
LABORATORY PROCEDURES	
Calculate distance from stadia readings. Convert polar coordinates (distance, horizontal angle, vertical angle) to cartesian coordinates (North, East, and Z elevation). Subtract middle stadia reading. Record 3 pieces of information.	* Conversions performed by total station at time of reading.
Add the station coordinates and instrument height to each point shot from that station. Record 3 pieces of information.	* Conversions performed by total station at time of reading.
	Transfer raw data from HP-71B to Macintosh Change data to EXCEL text format.
Perform consistency checks for errors. Correct any errors, edit, and repeat previous 2 steps.	Read data into EXCEL. Use spreadsheet and database functions to validate, test, correct, and transform data. Output correct data. Print hardcopy listing, and back up on 800 KByte diskette.
Plot each point on graph paper, using an engineers rule or counting blocks on North (Y- axis) and East (X-axis). Write the elevation next to the point.	Run program PLOTPRT to plot data on the ImageWriter,with Z elevation or interval category label next to the point.
Draw the working contours.	Draw contours or run contouring software.
Draw natural, cultural, and archaeological features.	Use Computer Aided Drafting (CAD) software to add features.
Draft the final map(s).	Output final map to high resolution LaserWriter or Pen plotter.

Figure 28.7: A comparison of computer-assisted surveying and optical theodolite surveying.

Figure 28.8: Macintosh generated map of Southeast Asia showing the location of the Khao Wong Prachan (KWP) valley.
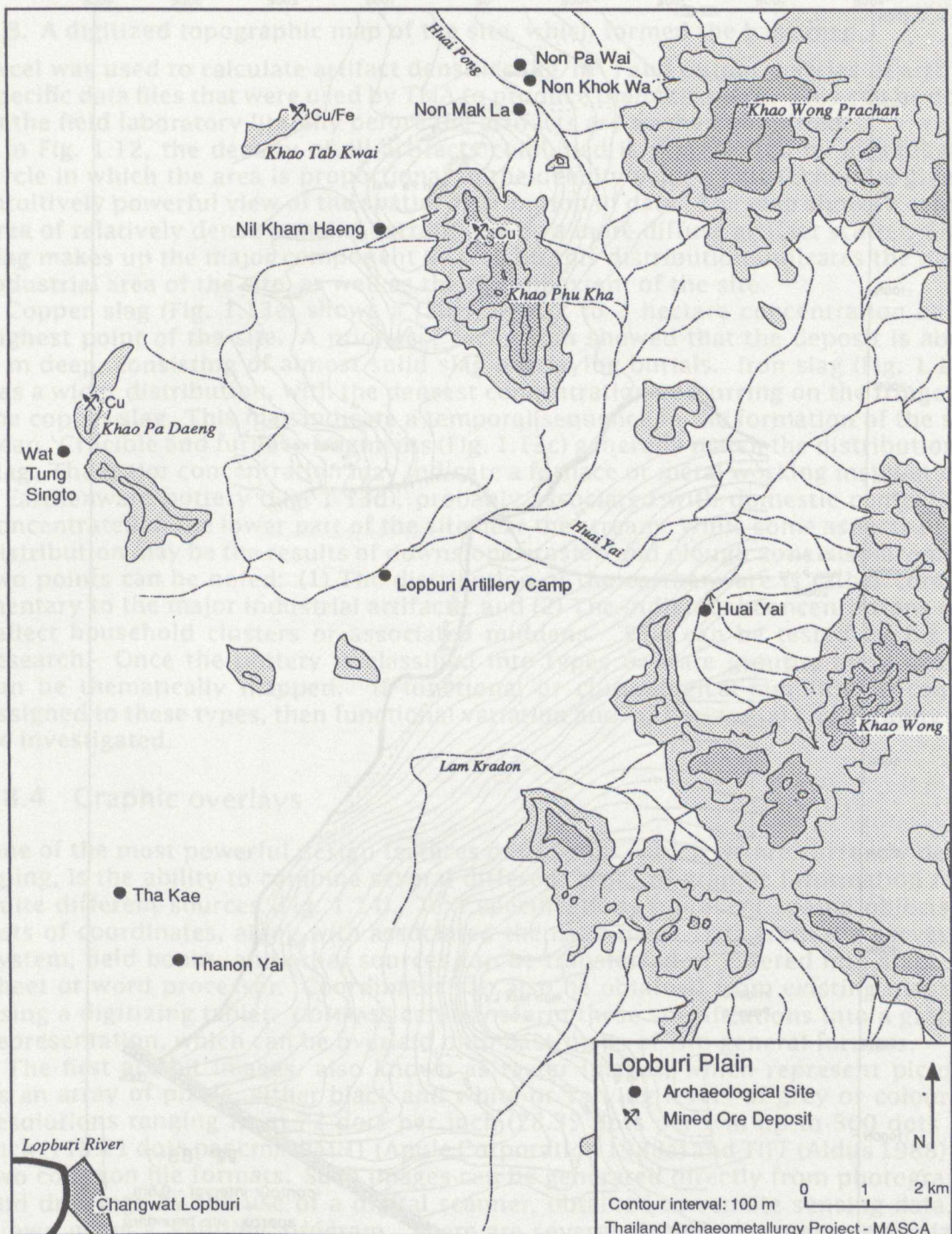
Figure 28.9: Macintosh generated regional map of the Thailand Archaeometallurgy Project study area in the Khao Wong Prachan (KWP) valley.
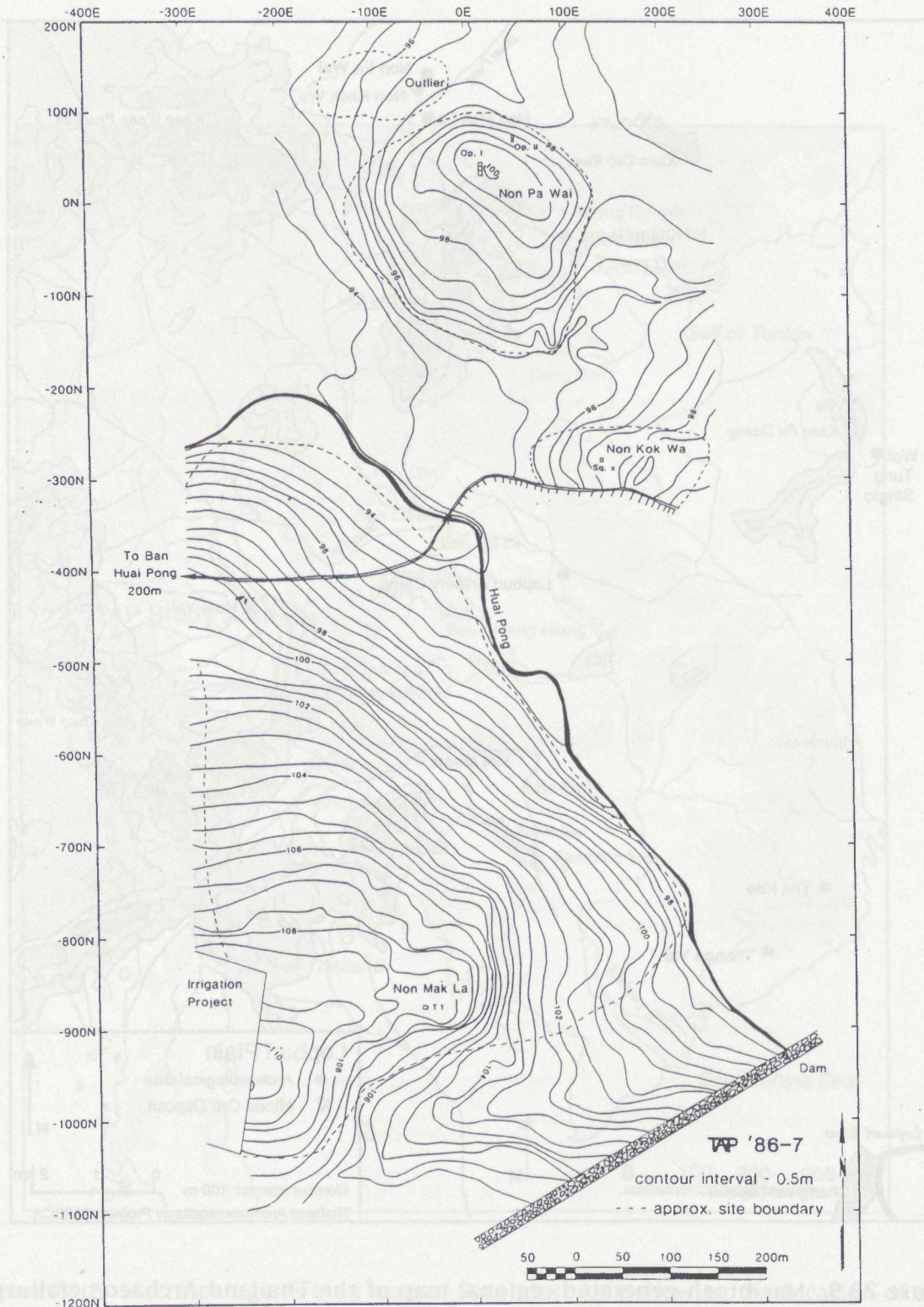
Figure 28.10: Final drafted topographic map of Non Pa Wai and Non Mak La.

3. A digitized topographic map of the site, which formed the base map.

Excel was used to calculate artifact densities (kg/m^2) and output a series of artifact specific data files that were used by TMA to produce thematic maps. This can be done in the field laboratory literally before the artifacts are washed and dried.

In Fig. 1.12, the density of all artifacts combined is represented by a graduated circle in which the area is proportional to the density value. This technique gives a intuitively powerful view of the spatial distribution of data. The map shows a central area of relatively dense remains surrounded by a more diffuse artifact scatter. Since slag makes up the major component by weight, this distribution indicates the major industrial area of the site, as well as the overall extent of the site.

Copper slag (Fig. 1.13a) shows a fairly tight 2 to 3 hectare concentration at the highest point of the site. A prior test excavation showed that the deposit is about 1 m deep, consisting of almost solid slag overlaying burials. Iron slag (Fig. 1.13b) has a wider distribution, with the densest concentrations occurring on the fringes of the copper slag. This may indicate a temporal sequence in the formation of the slag heap. Crucible and furnace fragments (Fig. 1.13c) generally match the distribution of slag. The major concentration may indicate a furnace or metal working installation.

Earthenware pottery (Fig. 1.13d), probably associated with domestic contexts, is concentrated in the lower part of the site near the stream. While some aspects of the distribution may be the results of downslope erosion and plough zone displacement, two points can be noted: (1) The distribution of the earthenware is rather complementary to the major industrial artifacts; and (2) The individual concentrations may reflect household clusters or associated middens. This can be tested by fut ure research. Once the pottery is classified into types or ware groups, these groups can be thematically mapped. If functional or chronological significance can be assigned to these types, then functional variation and/or horizontal stratigraphy can be investigated.

28.4 Graphic overlays

One of the most powerful design features of COMPASS, which we are currently developing, is the ability to combine several different types of graphic information from quite different sources (Fig. 1.14). Text specifications represent spatial objects by lists of coordinates, along with associated thematic data. Data from the surveying system, field books, and other sources can be transferred or entered into a spreadsheet or word processor. Coordinates can also be obtained from existing maps by using a digitizing tablet. COMPASS can transform these specifications into a graphic representation, which can be overlaid onto base maps of two general formats.

The first are bit images, also known as raster images, which represent pictures as an array of pixels, either black and white or varying levels of grey or colour, in resolutions ranging from 72 dots per inch (28.35 dots per cm) up to 300 dots per inch (118.11 dots per cm). PAINT (Apple Corporation 1988a) and TIFF (Aldus 1988) are two common file formats. Such images can be generated directly from photographs and drawings by the use of a digital scanner, obtained as remote sensing data, or drawn using a 'Painting' program. There are several Macintosh programs available for touching up and transforming grey scale digital images.

Object oriented graphics, also known as vector graphics, define geometric objects mathematically as coordinate sets and relationships between points. PICT (Apple Corporation 1988b) and PostScript (Adobe Systems 1985) files are common file formats. They can be generated by tablet digitizers, or drawn using CAD programs. A more recent development are programs geared toward precision tracing of scanned bit images. Object oriented graphics have the important advantage of scaling cleanly, and printing at extremely high quality on Laser printers or typesetting machines.
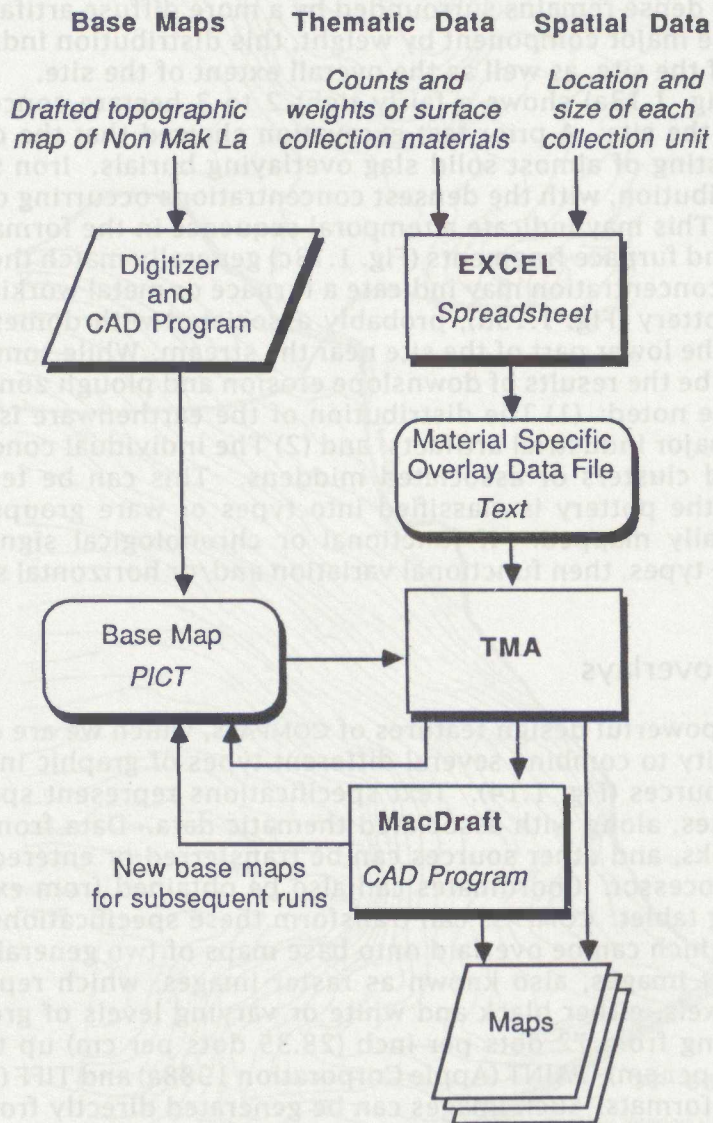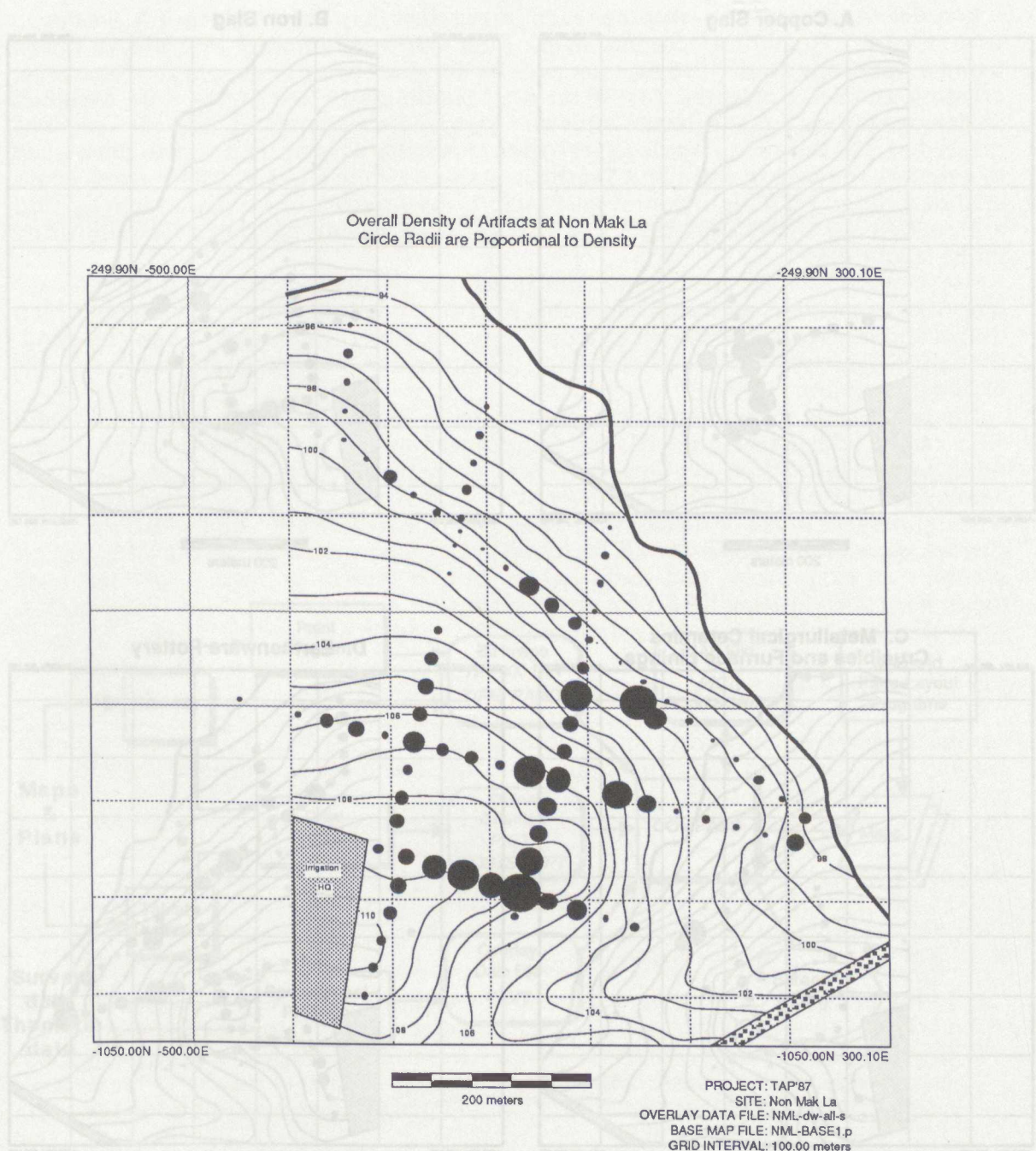
Base Maps **Thematic Data** **Spatial Data**

Drafted topographic map of Non Mak La

Counts and weights of surface collection materials

Location and size of each collection unit

Digitizer and CAD Program

EXCEL
Spreadsheet

Material Specific Overlay Data File
Text

Base Map
PICT

TMA

New base maps for subsequent runs

MacDraft
CAD Program

Maps

Figure 28.11: Flow diagram for generating the thematic maps shown in Figs. 1.11 and 1.12.

Overall Density of Artifacts at Non Mak La
Circle Radii are Proportional to Density

-249.90N -500.00E   -249.90N 300.10E

-1050.00N -500.00E   -1050.00N 300.10E

200 meters

PROJECT: TAP'87
SITE: Non Mak La
OVERLAY DATA FILE: NML-dw-all-s
BASE MAP FILE: NML-BASE1.p
GRID INTERVAL: 100.00 meters

TMA Release 1.0 ....Museum Applied Science Center for Archaeology (MASCA), The University Museum.........Thu, Feb 4, 1988 ... 10:57 AM

Figure 28.12: Thematic map showing the combined surface distribution of material at Non Mak La. The area of the circle are proportional to the density (kg/m^2) in each of the 92 collection units.
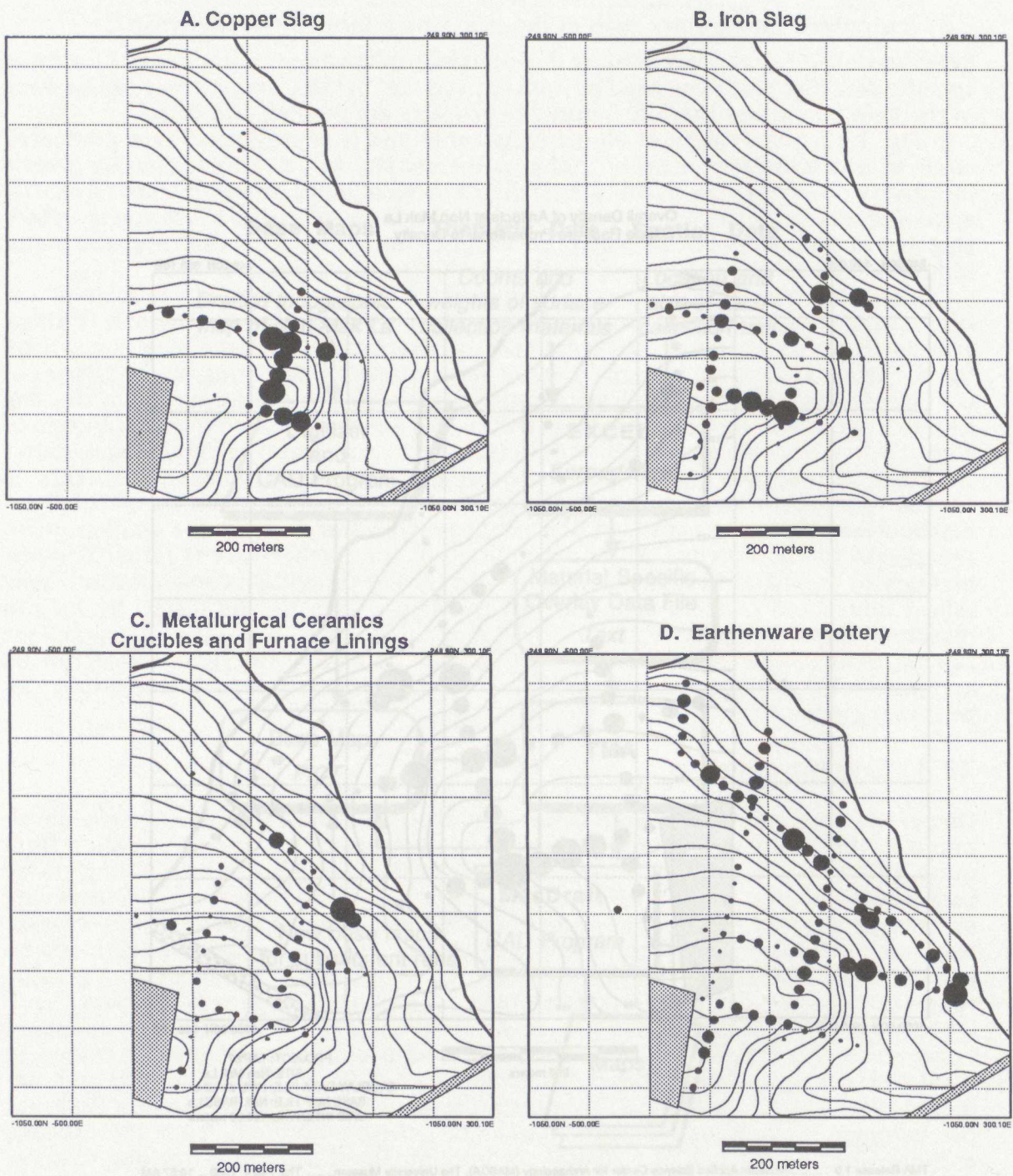
Figure 28.13: Thematic map showing the surface distributions of individual material classes at Non Mak La. The area of the circle are proportional to the density (kg/m²) in each of the 92 collection units. (A) Copper Slag. (B) Iron Slag. (C) Crucibles and Furnace Fragments. (D) Earthenware Pottery.
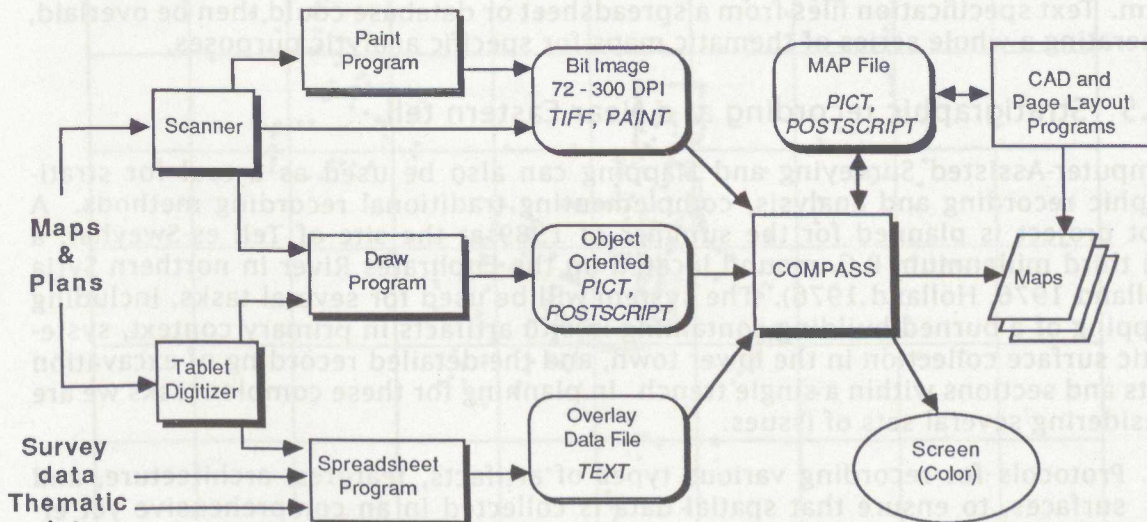
Paint Program

Scanner

Maps & Plans

Draw Program

Tablet Digitizer

Survey data
Thematic data

Spreadsheet Program

Bit Image 72 - 300 DPI *TIFF, PAINT*

Object Oriented *PICT, POSTSCRIPT*

Overlay Data File *TEXT*

MAP File *PICT, POSTSCRIPT*

CAD and Page Layout Programs

COMPASS

Maps

Screen (Color)

Figure 28.14: Flow chart of graphic overlay processing in COMPASS.

In order to generate the machine readable regional map shown in Fig. 1.9, we began with a Thai 1:50,000 topographic map. This map was scanned as a binary image using a DataCopy model 730 scanner. Adobe Illustrator was used to trace the image, creating an object oriented PostScript file. Shading and line styles were assigned to geographic features, selected sites and text labels were added, and the map was printed at 300 dpi on an Apple LaserWriter. A similar procedure has also been used to generate the map of mainland Southeast Asia shown in Fig. 1.8. These maps could also be printed on a high resolution PostScript typesetter, or be made directly into a 35mm colour slide. Illustrator can also generate colour separates for publishing multi-colour maps.
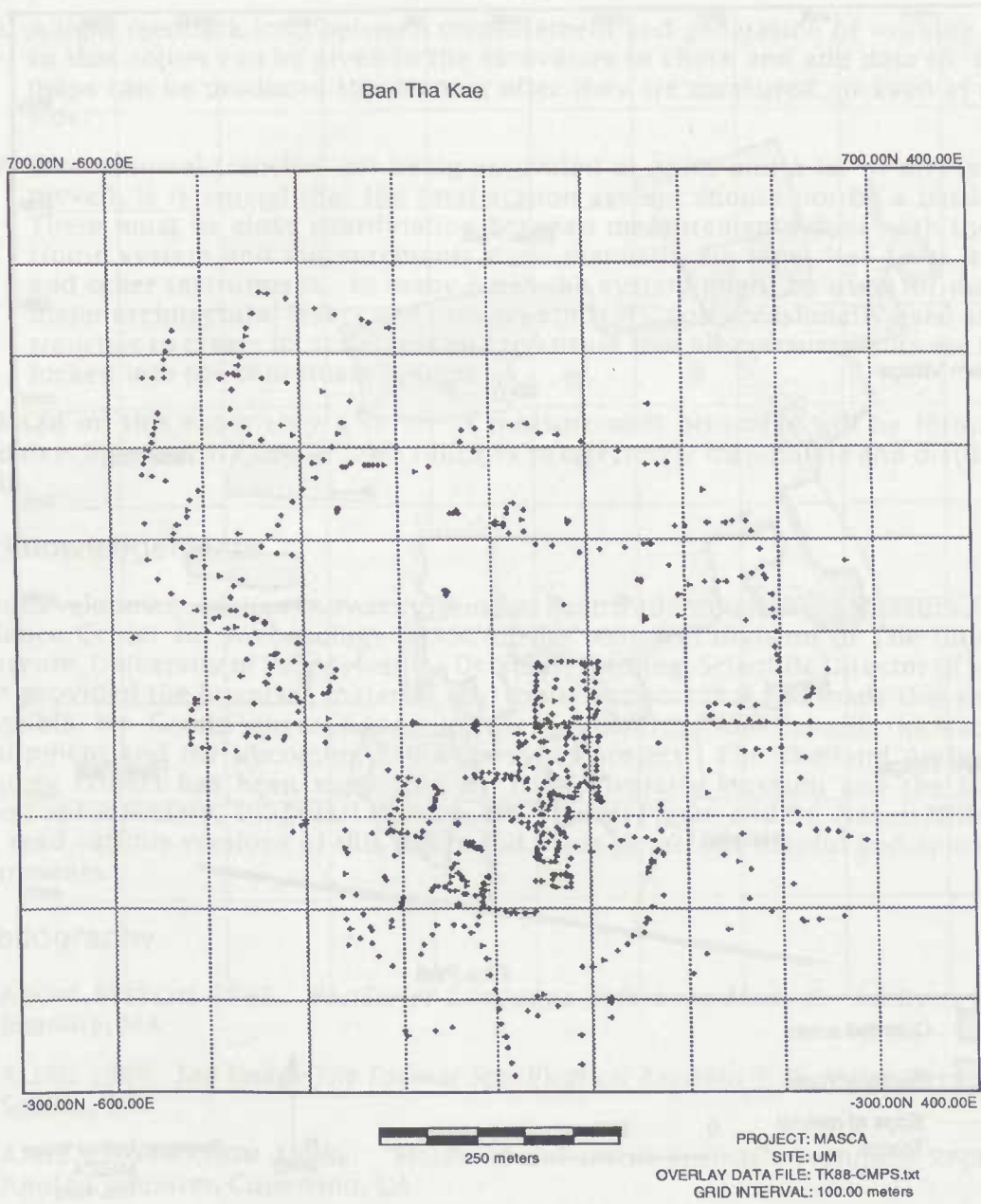
Site maps can also be created in a similar manner. A survey point plot from COMPASS (Fig. 1.15), output as a machine readable PICT file, is used as the template, and then drawn and labeled by Adobe Illustrator (Fig. 1.16). Final stippling was done by hand, though in principle it can be done using an integrated 300 dpi paint and PostScript drawing program.

The advantage of computer generated maps is that they can be easily modified. Sites can be added and removed, and represented by different symbols and colours. Additional information, such as soil types or vegetation cover, can be selectively displayed. Several display techniques at several scales can be experimented with. While at present much of the composition is done interactively using a CAD package, current development efforts call for COMPASS to incorporate these high resolution graphics as base maps, and define a coordinate system or map projection over them. Text specification files from a spreadsheet or database could then be overlaid, generating a whole series of thematic maps for specific analytic purposes.

28.5 Stratigraphic recording at a Near Eastern tell

Computer-Assisted Surveying and Mapping can also be used as a tool for stratigraphic recording and analysis, complementing traditional recording methods. A pilot project is planned for the summer of 1989 at the site of Tell es-Sweyhat, a late third millennium B.C. mound located on the Euphrates River in northern Syria (Holland 1976, Holland 1976). The system will be used for several tasks, including mapping of a burned building containing in-situ artifacts in primary context, systematic surface collection in the lower town, and the detailed recording of excavation units and sections within a single trench. In planning for these complex tasks we are considering several sets of issues:

1. Protocols for recording various types of artifacts, features, architecture, and surfaces, to ensure that spatial data is collected in an comprehensive yet efficient manner, and so that the geometrical relationships can be intelligently manipulated by COMPASS. These measurement protocols can be implemented both within the total station data collection program, and through field forms.

2. Routines to assist in using the surveying equipment for section drawing.

3. How to capture the 3-dimensional extent of both natural and arbitrary excavation units. These data can be used to generate stratigraphic orderings such as Harris matrices (Harris 1979), compute the volume of each unit to calculate density ratios of artifacts per cubic metre of deposit (Miller 1988), and correlate units as excavated in plan with stratigraphic sections.

4. How to display spatial data using a combination of plan views, sections (both recorded as sections and derived from elevations) and 3-dimensional perspectives.

Ban Tha Kae

700.00N -600.00E   700.00N 400.00E

-300.00N -600.00E   -300.00N 400.00E

250 meters

PROJECT: MASCA
SITE: UM
OVERLAY DATA FILE: TK88-CMPS.txt
GRID INTERVAL: 100.00 meters

TMA Release 2.0   ....Museum Applied Science Center for Archaeology (MASCA), The University Museum.Tue,.Nov 1, 1988 ... 10:42 AM

Figure 28.15: Point plot of the site of Tha Kae, surveyed and plotted using the COMPASS system, and used a the template for the final map shown in Fig.   16.

Ban Tha Kae

Figure 28.16: Final map of Tha Kae drawn with Adobe Illustrator using Fig. 1.15 as the template.

5. The ability to incorporate pre-existing drawings and photographs of plans, sections, and architecture into the system.

6. A tight feedback loop between measurement and generation of working maps, so that copies can be given to the excavators to check and add data to. Ideally maps can be produced the evening after they are measured, or even at trench side.

7. When several trenches are being excavated at once, and a lot of dirt is being moved, it is crucial that the total station system should not be a bottleneck. There must be close coordination between measurements done with the electronic system and measurements done manually via tape, line level, transit, and other instruments. In many cases the system might be used for mapping major architectural layers and primary contexts, and occasionally used at other trenches to create local datums and to ensure that all measurements are tightly locked into the coordinate system.

Based on this experience a series of measurement protocols will be formalized, and development will continue on routines to effectively manipulate and display this data.

Acknowledgements

Bibliography

ADOBE SYSTEMS 1985. *PostScript Language Reference Manual.* Addison Wesley, Reading, MA.

ALDUS 1988. *Tag Image File Format Specification Revision 5. 0.* Aldus Corporation, Seattle, WA.

APPLE CORPORATION 1988a. "MacPaint Document Format", Technical Report 86, Apple Computer, Cupertino, CA.

APPLE CORPORATION 1988b. "QuickDraw's Internal Picture Definition", Technical Report 21, Apple Computer, Cupertino, CA.

BERTIN, J. 1983. *Semiology of Graphics.* University of Wisconsin Press, Madison, WI.

BINFORD, L. R. 1964. "A Consideration of Archaeological Research Design", *American Antiquity*, 29: 425–441.

HARRIS, E. C. 1979. *Principles of Archaeological Stratigraphy.* Academic Press, New York, NY.

HOLLAND, T. 1976. "Preliminary Report of the Excavations at Tell es-Sweyhat, Syria, 1973-4", *Levant*, 8: 36–70.

MILLER, N. 1988. "Ratios in Paleoethnobotanical Analysis". *in* Hastorf, C. A. & Popper, V. S., (eds.), *Current Paleoethnobotany*, pp. 72–85. University of Chicago Press, Chicago, IL.

PIGOTT, V. C. & S NATAPINTU 1988. "Archaeological Investigations into Prehistoric Copper Production: The Thailand Archaeometallurgy Project". *in* Maddin, R., (ed.), *The Beginnings of the Use of Metals and Alloys*. M. I. T. Press, Cambridge, MA.

ROBINSON, A. H., R. D. SALE, J. L. MORRISON, & P. C. MUEHRCKE 1984. *Elements of Cartography, Fifth Edition*. Wiley, New York.

TUKEY, J. W. 1977. *Exploratory Data Analysis*. Addison Wesley, Reading, MA.